Solving the problem of switching from one track gauge to another in the context of the requirements of interoperability specifications for classical infrastructure

Maxim Arbuzov, *Volodymyr* Andrieiev*, and *Stanislav* Kosturechko

Ukrainian State University of Science and Technology, Department of Transport Infrastructure, 49010 Dnipro, Lazaryana Street 2, Ukraine

Abstract. The article discusses issues related to solving the problem of switching from one gauge to another. A progressive solution to the problem of different track gauges is the use of a combined gauge design. The combined track solves the problems of overloading, downtime, and wheel set problems. The design of the combined gauge has set new challenges for track infrastructure workers and scientists. The first task is the strength of the combined track structure. The second task is the stability of the combined track plates. The third task is to lay switches in the combined track and determine the permissible train speeds.

1 Introduction

The process of European integration requires studying and applying the regulatory documents of the European Union. The implementation of European standards is now widely used in practice. An important aspect is the interoperability of technical systems.

Today, railroad employees are studying the Technical Interoperability Specifications for classical infrastructure and its maintenance, in particular Commission Regulation (EU) No 1299/2014 of November 18, 2014 on technical specifications for interoperability relating to the 'infrastructure' subsystem of the railway system in the European Union [1]. This issue addresses the problems of switching from one gauge to another. The gauge is measured between the working faces of two rails. The rolling stock of Polish railways is designed for a track gauge of 1535 mm. Ukrainian railways have a track gauge of 1520 mm. Polish rolling stock cannot enter Ukrainian railways, and Ukrainian rolling stock cannot enter Polish railways. Therefore, there is a problem of technical incompatibility of gauge. This problem is solved by various methods.

To transport goods from one country to another that have different track gauges, transshipment is used. It is convenient to reload cargo in containers. This technology forms a containerized cargo transportation system and does not solve the problem of different track gauges.

Previously, there was a system of sliding SUW wheelsets. This system was aimed at solving the problem of different track gauges. However, the complexity of operating and repairing the SUW system has led to the fact that it is not used today. The solution to the track gauge problem has created a safety issue in rail transport.

2 Combined track work

The system of replacing bogies under the cars is used. The car is lifted, bogies designed for a track gauge of 1520 mm are rolled out, and bogies designed for a track gauge of 1435 mm are rolled in. There are problems with the lifting mechanisms and the speed of such operations. This technology takes a lot of time. It is not possible to increase the speed of the lifting mechanisms. Increasing the number of lifting mechanisms is a financially expensive solution.

For the transportation of goods from one country to another with different gauge standards A progressive solution to the problem of different track gauges is the use of a combined track structure (Figure 1). A rail and sleeper grid made of four rails, sleepers and fasteners is laid within one subgrade. One pair of rails has a track gauge of 1520 mm, the other pair of rails has a track gauge of 1435 mm.

The combined track solves all of the above problems of overloading, downtime, and wheel set problems.

Fig. 1. Section of combined 1520 and 1435 mm rail gauge

The total length of the combined rail gauge (1520 mm and 1435 mm) on the Lviv Railway is 153.4 km. Such a track is laid on the sections State border - Mostiska-II -

* Corresponding author: avsdiit@gmail.com

Rodatychi, State border - Chop - Batyevo, State border - Yahodyn - Kovel. These sections are part of the international transport borders (Krytskyi No. 3 and 5, Hradsk - Odesa).

Two double-track electrified railway lines connecting Lviv with European countries end in sections with combined gauge. The first of these lines, 84 km long, passes through Mostyska-II station and is the shortest connection to Poland, Slovakia, the Czech Republic, Germany and other Central European countries, as well as Scandinavia. The railway line Lviv - Mostyska-II - State Border is a part of the third trans-European transport corridor (Berlin - Wroclaw - Przemysl - Lviv - Kyiv) and at the same time a part of the international line E30 covered by the AGC agreement.

The second line, 266 km long, passes through Chop and connects Ukraine with Slovakia, Bulgaria, Romania, and other countries in Central and Southern Europe.

However, the design of the combined track posed new challenges for track infrastructure workers and scientists. The first challenge is the strength of the combined track structure. The second task is the stability of the combined track plates. The third task is to lay switches in the combined track and determine the permissible train speeds.

Permissible temperature drop from the rail strength condition.

For conventional jointless track, the permissible temperature drop from the condition of rail strength is given in the "Technical instructions for the arrangement, laying, repair and maintenance of jointless track on the railways of Ukraine" [2] for different rolling stock units, different track layouts, rail types, and different speeds [9]. The values $[\Delta t_p]$ are determined for a jointless track with non-hardened rails of the P65 type of the first service life on reinforced concrete sleepers and crushed stone ballast. For hardened rails of the P65 type of the first service life, the value of $[\Delta t_p]$ is increased by 20°C, and for old rails on the main tracks it is reduced by 5°C [2]. The value of "5°C" is actually variable and depends on the amount of stress in the rail sole due to the action of the rolling stock. This value is taken as the largest value that goes into the safety margin.

When determining the permissible temperature drop from the rail strength condition for a combined buttless track, the first problem is the lack of "Rules for calculating the combined track for strength". Today, for the combined track, it is necessary to clarify the methods of calculating stresses at the edge of the rail sole, at the edge of the rail head, on the sleeper under the substrate, in the ballast under the sleeper, and on the main subgrade. These studies require both the development of a new model of interaction between rolling stock and track and experimental trips of different types of rolling stock to verify the developed theoretical positions and determine the elastic modulus of the subgrade.

But even in the absence of the "Rules for calculating the strength of combined track", it is obvious that

1) the rail and sleeper grid of a combined track is more rigid than a conventional track;

2) for two rails loaded by the action of rolling stock wheels, the subgrade base takes the form of a frame due to the presence of two more rails attached to the sleepers;

3) the elastic modulus of the subgrade U for the combined track is higher than for the conventional track.

According to the "Rules for Calculating Railway Track for Strength and Stability" [3], the average value of the elastic modulus of the subgrade for conventional track for the KPP-5 in winter is 75.6 MPa.

The operation of the subgrade in the area of the connecting part of the turnout is similar to the operation of the subgrade of a combined track, since there are two loaded and two free rails attached to a common bar. As a first approximation, the elastic modulus of the subgrade of the combined track U is the elastic modulus of the subgrade of the connecting part of the turnout for winter conditions with reinforced concrete bars. So, we assume that the elastic modulus of the subgrade of the combined track base U = 95.3 MPa [3].

Let's perform a strength calculation for a conventional (2-strand) track and a combined (4-strand) track. According to calculations $[\Delta t_p]$ for the combined track on 2°C is greater than $[\Delta t_p]$ for the conventional track.

Consequently, for a combined jointless track, $[\Delta t_p]$ should be increased by 2°C compared to the values given in the "Technical instructions for the arrangement, laying, repair and maintenance of jointless track on the railways of Ukraine" [2].

Let's perform calculations using computer modeling to confirm that the stresses in the rails of the jointed track are lower than in the conventional track.

The strength and stability of a railroad track is determined in accordance with regulatory requirements [3]. However, the methodology for calculating a railroad track does not provide for a four-rail structure. Therefore, this problem must be solved by means of finite element modeling. The finite element method (FEM) is the main method of modern structural mechanics and is the basis of the vast majority of modern software packages, including the Slid Edge program.

To verify the operation of the model of a conventional track with a width of 1520 mm in Solid Edge over a wide range of vertical loads, calculations were performed for different values of the design force P_{roz}. The study of the stresses in the rail head due to load changes in the PUT program, which is based on the methodology of the normative document [3], and Solid Edge is shown in Table 1. The results show that modeling in Solid Edge is applicable.

Table 1. Study of stresses along the rail head axis

P_{roz}, kN	$\sigma_{\text{Solid Edge}}$, MPa	σ_{PUT}, MPa	Error, %
119,8	65,39	67,21	2,7
129,4	70,63	72,86	3
139,1	77,06	78,62	1,9
149,3	81,49	84,75	3,8
157,4	85,89	89,56	4

When modeling the combined gauge (Figure 2), the same simplifications were used as for the conventional 1520 mm gauge. The differences between the models are

in the type of sleepers: for the 1435 mm and 1520 mm gauge, 2850 mm long Sh2C-1 sleepers were used, and the ballast dimensions were changed. The length of the model remained unchanged.

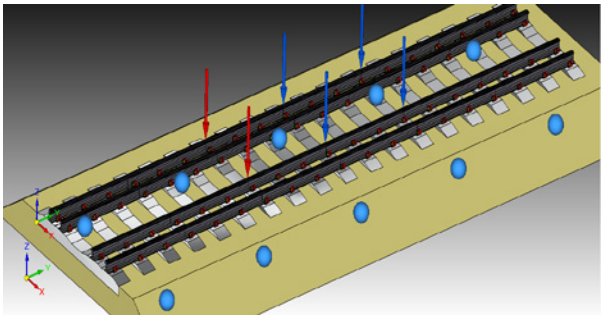

Fig. 2. Model of combined 1435 and 1520 mm gauge in Solid Edge

The Solid Edge simulation shows that the stresses in the loaded rails of the combined track along the rail head axis are 78.615 MPa. Determine the difference in stresses in the rail heads between the conventional track and the combined track: 85.897 - 78.615 = 7.282 MPa. Thus, the stresses in the rails of the combined track are 8% lower than in the conventional track. The stress in the unstressed rail of the combined track is less than 1 MPa.

Permissible temperature drop under the condition of maximum gap opening in case of rail breakage and under the condition of ensuring the strength of the butt bolts of the equalizing spans.

For combined gauge rail ties, the linear resistance to rail movement along sleepers, rail cross-sectional area, elastic modulus, linear expansion coefficient, and resistance in butt bolts do not differ from the corresponding parameters of conventional jointless rail. For rail slabs of combined track, the parameter A is also: 0.00968 for P65 rails; 0.00899 for UIC60 rails.

Therefore, the values of the Technical Guidelines [2] can be used to calculate the temperature interval for fixing the plates of the combined buttless track. At the same time, the only condition for the legitimacy of using these Technical Guidelines [2] is to ensure that the intermediate fasteners used on the combined track have a standard running resistance of 25 kN/m.

Determination of admissible temperature increase from the condition of stability of a combined long welded track.

The stability of a jointless combined track differs from that of a conventional track. The temperature force in the jointed track is twice as high, and the horizontal stiffness of the rail and sleeper grid is also higher.

For a combined jointless track, the permissible temperature rise from the stability condition is written as

$$[\Delta t_c^c] = \frac{[P_{t-c}^c]}{4 \cdot \alpha \cdot E \cdot F_1}, \quad (1)$$

$[P_{t-c}^c]$ – permissible temperature force from the stability conditions of the combined jointless track;
F_1 – cross-sectional area of one rail;
α – linear expansion coefficient (α=1,18·10^{-5} 1/°C);
E – modulus of elasticity of rail steel (E=2,1·10^5 MPa);
4 – number of rail threads.

The permissible temperature force from the stability conditions of a conventional jointless track is determined from the expression

$$[P_{t-c}^з] = \frac{P_з^з}{k_c}, \quad (2)$$

$P_з^з$ – is the critical temperature force at which a conventional jointless track is ejected;
k_c – permissible stability factor, 1,5.

The permissible temperature force from the stability conditions of the combined jointless track is determined from the expression

$$[P_{t-c}^c] = \frac{P_з^c}{k_c}, \quad (3)$$

$P_з^c$ – is the critical temperature force at which the combined jointless track is ejected;
k_c – permissible stability factor, 1,5.

Then you can write down

$$[\Delta t_c^c] = \frac{P_з^c}{P_з^з} \cdot \frac{[\Delta t_c^з]}{2}. \quad (4)$$

Let us choose a method for calculating the critical temperature force.

The closing temperature force, at which the ejection occurs, has been determined by many authors of the theory of operation of a continuous track: K.M. Mishchenko, A.A. Kryvobodrov, S.P. Pershin, O.Y. Kogan, S.I. Morozov, M.F. Verigo, V.I. Novakovich, V.O. Grishchenko, E.M. Bromberg, V.G. Albrecht, M.P. Vinogorov, Z.A. Kreinis, E.I. Danilenko, M.I. Karpov, O.M. Patlasov, V.P. Shramenko. However, the expressions where the closing force is determined through the stiffness of the rail and sleeper lattice are complex. Thus, according to the formulas of K.N. Mishchenko [4]

According to K. Eswald [3], the critical temperature force is determined by the formula

$$\left.\begin{aligned} q &= \frac{P_з^2 \sqrt{1+\frac{P_з}{4pl}}}{7{,}18E\sqrt{I_{рш-г} \cdot 2F}} + \frac{P_з}{R} \\ l &= 13{,}92\sqrt{\frac{EI_{рш-г}}{P_з}} \end{aligned}\right\}, \quad (5)$$

p – the longitudinal resistance to the longitudinal movement of the rail and sleeper grid;
q – the linear resistance to the transverse movement of the rail and sleeper grating;
l – the wavelength of the ejection distortion;
E is the elastic modulus of rail steel;
$I_{рш-г}$ - is the moment of inertia of the rail and sleeper grid in the horizontal plane;
F – the cross-sectional area of the rail;
R – the radius of the curve.

$$P_з = 2 \cdot \sqrt{\frac{EI \cdot \tau_0}{\pi \cdot \left(f_0 + \frac{15}{R}\right)}}. \quad (6)$$

EI – horizontal stiffness of the rail and sleeper grid;
τ_0 – distributed resistance to lateral movement of sleepers;
f_0 – initial inequality;

R – curve radius.

The Sh2S sleeper of 1520 mm and 1435 mm combined gauge with KPP-5 type fastening weighs 368 kg, which is 1.4 times heavier than the Sh1 sleeper. The bearing area of the Sh2S sleeper is 1.08 times larger than that of the Sh1 sleeper. However, the laying pattern of Sh2S sleepers is 1520 pcs/km, which is 1.21 times less than that of conventional buttless track. The distributed resistance of sleepers to lateral displacement is known to be formed by both mass and grip. Therefore, as a first approximation, the distributed resistance τ_0 of sleepers of a combined track to lateral displacement is assumed to be equal to the distributed resistance to lateral displacement of sleepers of a conventional track.

For the most common modern standard designs of jointless track and operating conditions, it is possible to plot the dependence of the permissible temperature increase of rail plates on the radius of the curve (Figure 3). Also in Figure 3 also shows graphs of the dependence of the permissible temperature increase of rail plates $[\Delta t_c]$ on the radius of the curve, which were built according to the Technical Guidelines [5], according to calculations by Bromberg E.M. and Pershin S.P.

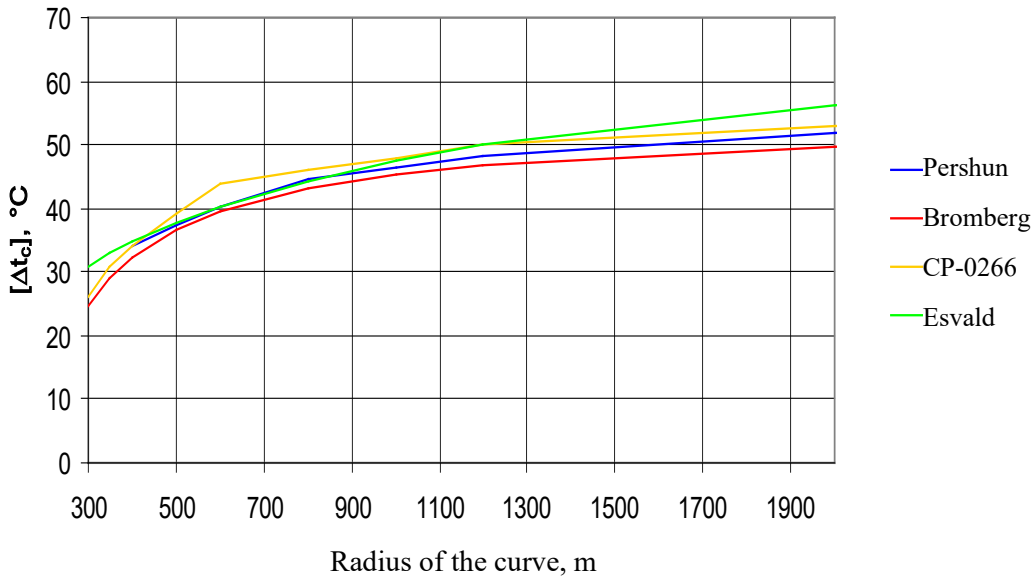

Fig. 3. Dependences of the permissible temperature increase of rail plates $[\Delta t_c]$ on the curve radius at the 1840 pcs/km epitome and P65 rails

$\Delta t_c]$ according to E.M. Bromberg, S.P. Pershin, according to the requirements of Technical Guidelines CP-0266 and according to K. Esvald have close values. Thus, according to the Eswald formula (6), which is analytical and simple, it is possible to determine the temperature increase of rail plates $[\Delta t_c]$.

In formula (4), let us substitute the closing forces expressed through formula (5) for conventional and combined jointless track, which are in the same conditions. That is, the radius of curvature R is the same, the value of the initial roughness f_0 is the same, and the distributed resistance to lateral movement of sleepers is the same τ_0. Then (4) will take the form

$$[\Delta t_c^c] = \sqrt{\frac{EI^c}{EI^3}} \cdot \frac{[\Delta t_c^3]}{2} \qquad (7)$$

EI^c – horizontal stiffness of the combined track;
EI^3 – horizontal stiffness of a conventional track.

The horizontal stiffness of the rail and sleeper grid was determined experimentally.

Experimental studies were conducted to determine the horizontal lateral stiffness of conventional and combined track according to the developed methodology.

Studies of the horizontal lateral stiffness of conventional jointless track were carried out on a 9483 mm long rail and sleeper grid, fasteners of the KB-65 type, and rails of the P65 type. The rail and sleeper grid was raised at points located 340 mm from the rail ends. The number of sleepers of type Sh1 is 18 pcs.

As a result of lifting from its own weight, the rail and sleeper grid was deformed, forming a deflection arrow (Figure 4).

Fig. 4. Investigation of horizontal lateral stiffness of conventional jointless track with fastening of KB-65 type

Studies of the horizontal lateral stiffness of the combined jointless track were carried out on a rail and sleeper grid 12505 mm long, fastening type KPP-5, rail

P65. The rail and sleeper grid was raised at points 760 mm from the rail ends. The number of sleepers of the Sh2C type is 19 pcs.

The average value of the bending arrow of the rail and sleeper grid of the conventional track is 142.5 mm, and the combined one is 235.9 mm.

Studies of the horizontal lateral stiffness of conventional jointless track with KPP-5.2 type fastening were carried out on a 12495 mm long rail and sleeper grid, rail P65. The rail and sleeper grid was raised at points located 590 mm from the rail ends. The number of sleepers of type Sh1 is 23 pcs.

The average bending arc of the rail and sleeper grid of a conventional gauge with a KPP-5.2 type fastener is 495.7 mm.

Experimental measurements of the stiffness of the rail and sleeper lattice are presented in Table 2.

Table 2. Calculation of the stiffness of rail and sleeper gratings

Type RSG	*EI*, kN/sm^2
Normal KB-65	40207421
Combined	78166162
Normal KPP-5.2	30379409

Based on the data obtained experimentally on the stiffness of the rail and sleeper grid of a conventional jointless track and a combined jointless track, we determine by formula (6) $[\Delta t_c^c]$ is the permissible temperature increase of the rail plates of the combined jointless track. The calculation result is presented in Table 3.

Thus, Table 3 shows the permissible temperature increases of rail plates of the combined jointless track with KPP-5 fastening [6] and 1520 pcs/km sleeper pattern, determined experimentally.

Table 3: Permissible temperature increases for rail plates of combined jointless track with fastening KPP-5

Rail type	Railroad ties sketch	Permissible temperature increase of the rail plates, taking into account the stability of the combined track [Δt_c], °C									
		in a straight line	in curves of radius, m								
			2000	1200	1000	800	600	500	400	350	300
P65	1520	40	37	35	33	32	31	27	24	22	18

Turnouts of design Dn 917 and design Dn 918 are used in a combined track, for which the permissible speed for sidings must be established.

The maximum speeds allowed on the Ukrainian railways network for passenger and freight trains depend on the track design and types of rolling stock. In this case, the speed of passenger and freight trains on the side tracks on turnouts made of P65 and P50 rails with 1/11 grade crossbars should not exceed 40 km/h [7].

Permissible speeds of trains in curves are established based on the condition of not exceeding the norms of permissible unburned accelerations at the design parameters of the track. The calculated permissible unburned acceleration for passenger trains, provided that the passengers ride comfortably, is 0.7 m/s^2. The nominal value of the unburned acceleration for freight trains, subject to technical and economic indicators, should be within ±0.3 m/s^2.

The permissible speeds of trains on switches to the lateral direction are determined as for a track of the same design on a run in a curve of the same radius as the radius of the transfer curve or cross curve, taking into account the absence of an outer rail elevation.

There is no outer rail elevation on the 1520 mm and 1435 mm gauge intertwining (Dn 917 and Dn 918).

The permissible speed of trains in the sidings, provided that the norms of permissible accelerations are not exceeded, is determined by the requirements of the regulatory document [7]:

Under this condition, the sidingspeed is:

at α=0,3 m/s^2

$$V^{\alpha=0,3} = 27,2 \text{ km/h}$$

at α=0,7 m/s^2

$$V^{\alpha=0,7} = 41,5 \text{ km/h}$$

Permissible speed when acceleration changes

$$V = 3,6\sqrt[3]{bR_{min}}\psi$$

b – the crew's estimated base, is accepted 17 m,
R_{min} – radius of the curve (for Dn 917 is 190 m, for Dn 918 - 200 m)
ψ – for freight - 0.3 m/s^3, for passenger - 0.6 m/s^3.

$V^{\psi=0,6} = 44,89$ km/h at R_{min}=*190* m

$V^{\psi=0,3} = 35,6$ km/h at R_{min}=*190* m

$V^{\psi=0,3} = 36,24$ km/h at R_{min}=200 m

The speed in the forward direction is 120 km/h, as in turnouts of grade 1/11.

Analyzing the data obtained in the calculations, we conclude that the permissible speeds of trains on the intertwined tracks (Dn 917 and Dn 918) are –

$$V^{\text{direct}} = 120 \text{ km/h}$$

$$V^{\text{side pass}} = 35 \text{ km/h}$$

$$V^{\text{side cargo}} = 25 \text{ km/h}$$

3 Conclusion

Thus, in the context of the implementation of European standards, a promising solution to the problem of switching from one track gauge to another is the use of a combined track. The calculations performed for the combined track confirm the strength and stability of the rail and sleeper grid and the set speeds of trains on switches.

References

1. COMMISSION REGULATION (EU) No 1299/2014 of 18 November 2014 on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union 02014R1299 — EN — 16.06.2019
2. Technichni vkazivky po ulashtuvanniu, ukladanniu, remontu i utrymanniu bezstykovoi kolii na zaliznyciach Ukrainy [Text]: CP-0266; zatv. Nakazom 3 033-C 01.02.2012.- Kyiv, 2012.- 150 p. [in Ukrainian]
3. Pravyla rozrachunkiv zaliznychnoi kolii na micnist' I stiikist' [Text]: CP-0117 – Kyiv, Transport Ukrainy, 2006- 168 p. [in Ukrainian]
4. Frishman M.A., Voloshko Yu.D., and Shardin N.P. Rozrachunky kolii na micnist' ta stiikist'. Navchalno-metodychnyi posibnyk. Dnipropetrovsk. 1968. – 124 p. [in Ukrainian]
5. Pravyla vyznachennia pidvyschennia zovnishnioi reiky I vstanovlennia dopustymych shvydkostei v kryvych diliankach kolii [Text]: CP-0236. – Kyiv, 2011. [in Ukrainian]
6. Relaxation of the Elastic Clamp in Rail Festenings (Scopus) // Special Issue on Up-to-Date Problems in Modern Railways/ Acta Politechnica Hungarica/ Vol. 19, No. 3, 2022 – P. 219–230. DOI: 10.12700/APH.19.3.2022.3.17
7. Pravyla technichnoi ekspluatacii zaliznyc' Ukrainy, nakaz № 411 20.12.96 iz zminamy. [in Ukrainian]
8. Coenraad Esveld. Modern Railway Track / Coenraad Esveld – MRT–Production, 2001. – 650 p.
9. O. Hubar, Study of the interaction of the railway track and the rolling stock under conditions of accelerated movement / O. Hubar, R. Markul, O. Tiutkin, V. Andrieiev, M. Arbuzov, O. Kovalchuk // Problems of the railway transport mechanics – Dnipro, 2020. P. 985